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(54) **ACOUSTIC RESONATOR AND METHOD OF MANUFACTURING THE SAME**

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H03H 9/17 (2006.01)
H03H 3/02 (2006.01)
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CPC ***H03H 9/173*** (2013.01); ***H03H 3/02*** (2013.01); ***H03H 9/02015*** (2013.01); ***H03H 9/174*** (2013.01); *H03H 9/02118* (2013.01); *H03H 2003/021* (2013.01); *H03H 2003/023* (2013.01)

(58) **Field of Classification Search**
CPC H03H 9/173
See application file for complete search history.

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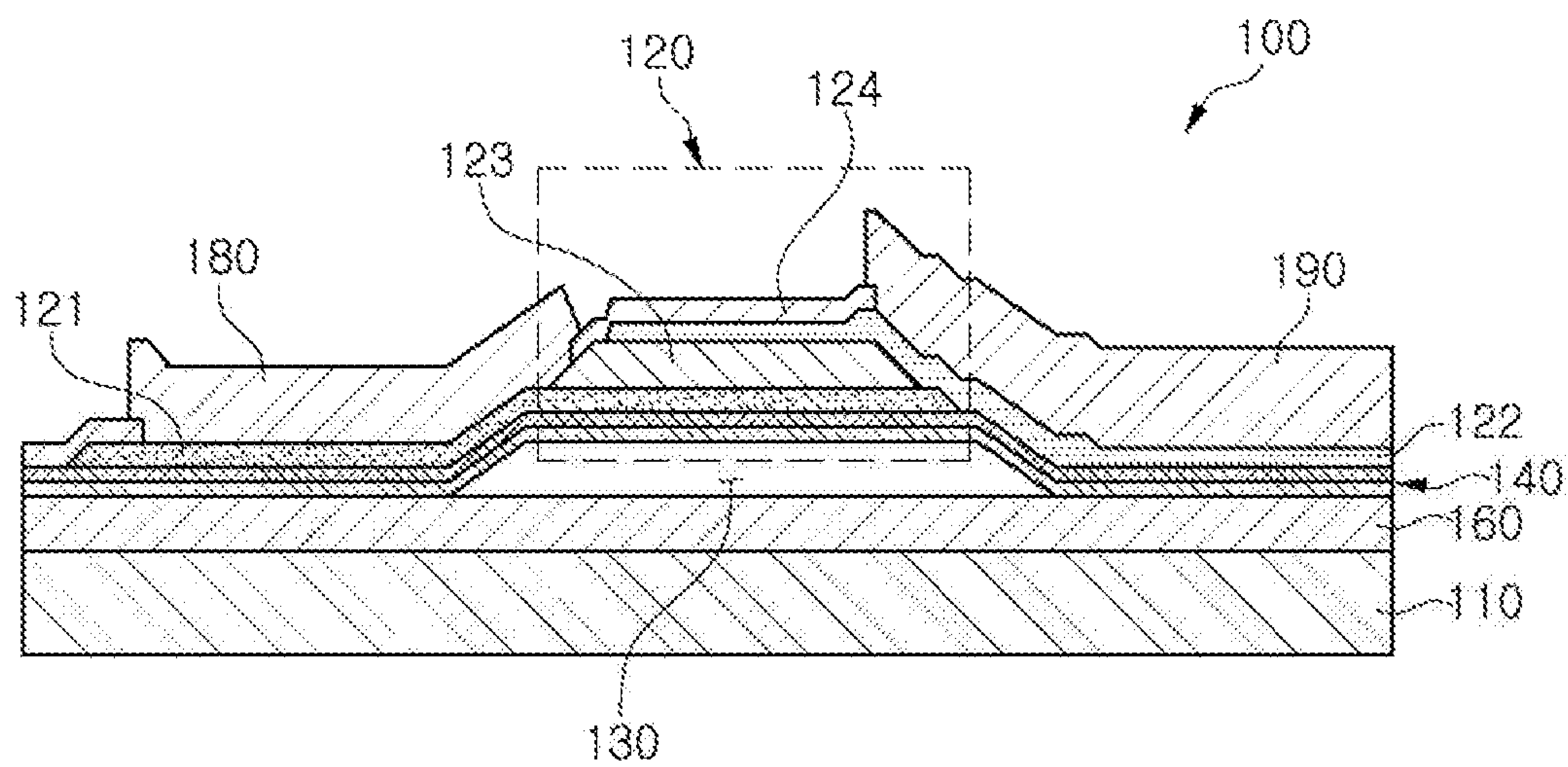
(57) **ABSTRACT**

An acoustic resonator and a method of manufacturing the same are provided. The acoustic resonator includes a resonating part including a first electrode, a second electrode, and a piezoelectric layer; and a plurality of seed layers disposed on one side of the resonating part.

17 Claims, 4 Drawing Sheets



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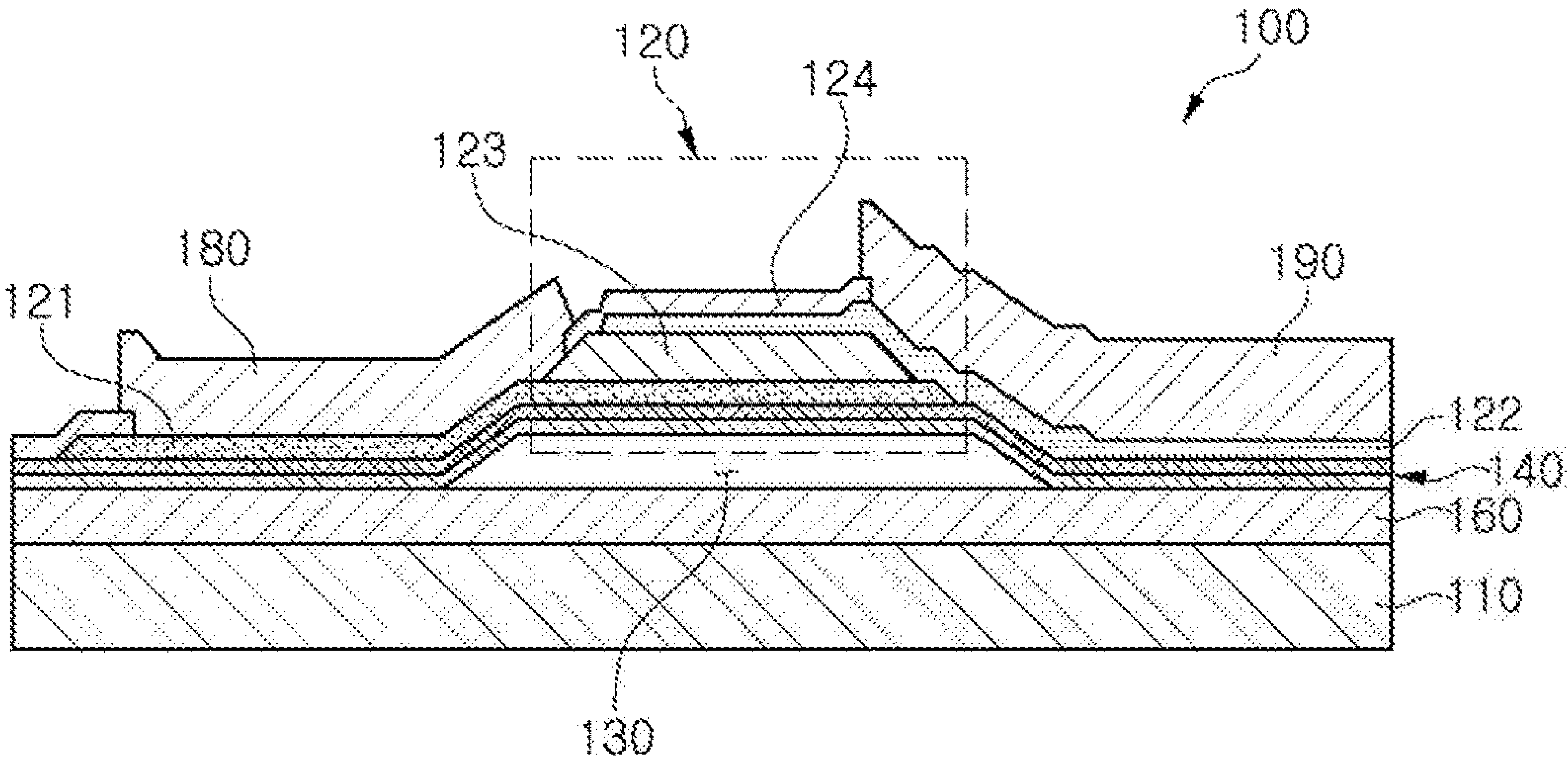
120
124
100
123
180
190
121
122
140
160
110
130

FIG. 1

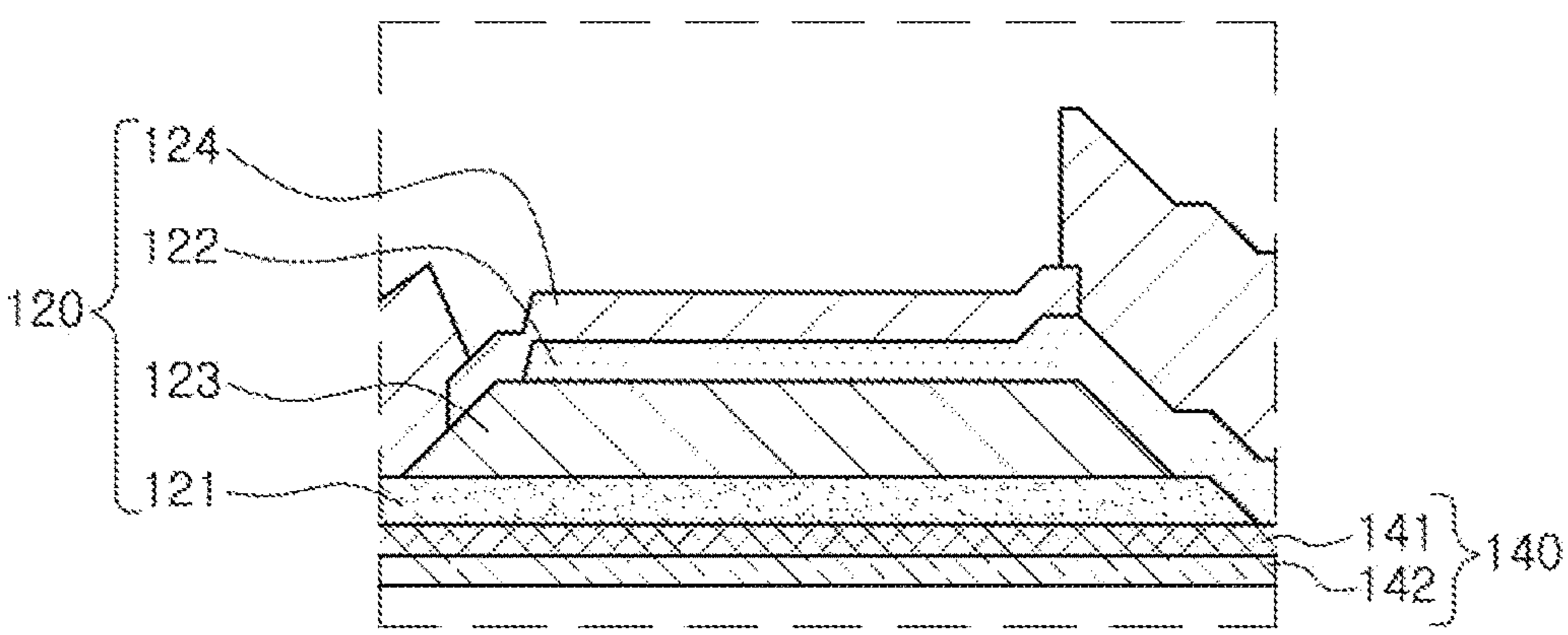
124
122
120
123
121
141
142
140

FIG. 2

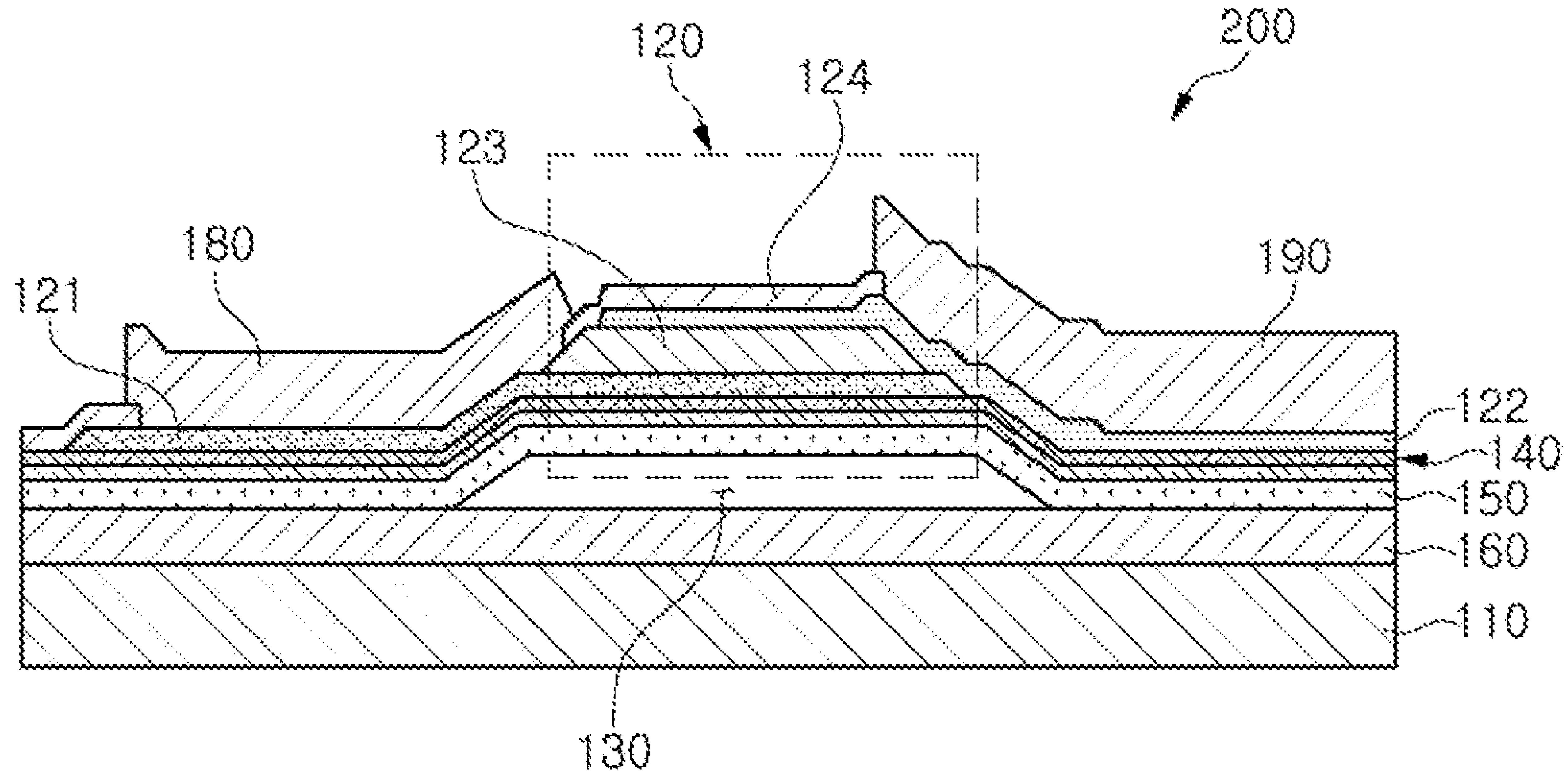
120
124
200
123
180
190
121
122
140
150
160
110
130

FIG. 3

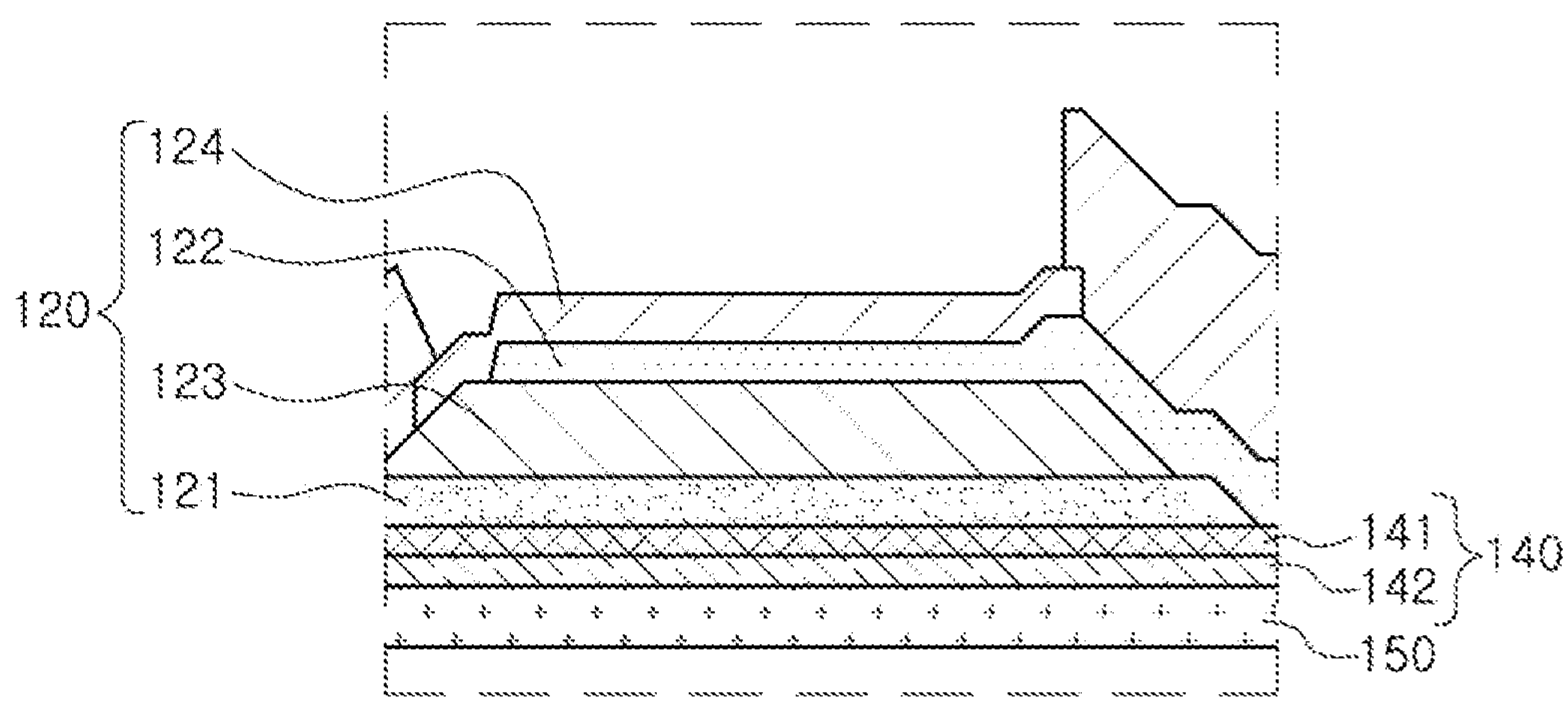
124
122
120
123
121
141
142
140
150

FIG. 4

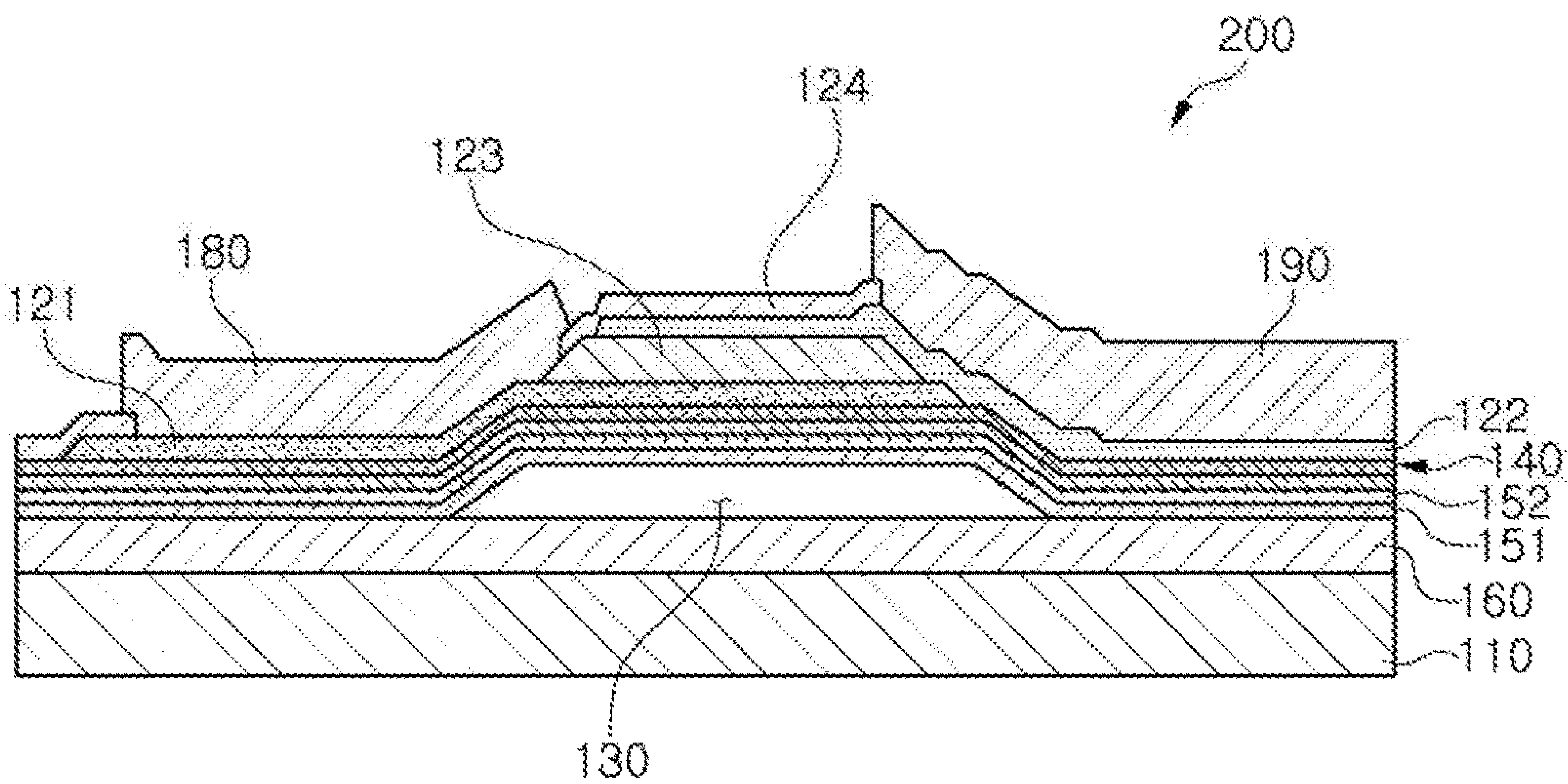

FIG. 5

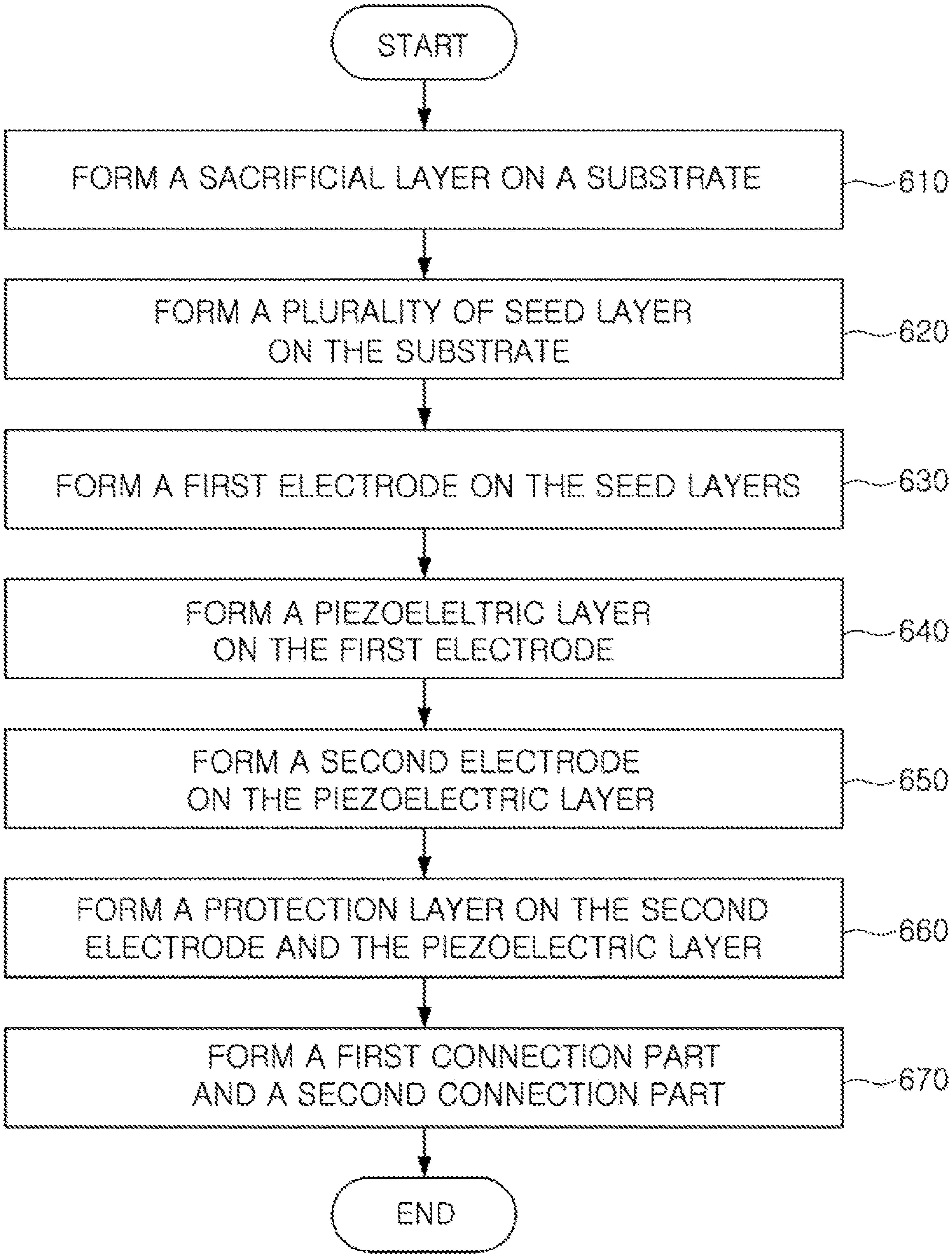
START
FORM A SACRIFICIAL LAYER ON A SUBSTRATE
610
FORM A PLURALITY OF SEED LAYER ON THE SUBSTRATE
620
FORM A FIRST ELECTRODE ON THE SEED LAYERS
630
FORM A PIEZOELELTRIC LAYER ON THE FIRST ELECTRODE
640
FORM A SECOND ELECTRODE ON THE PIEZOELECTRIC LAYER
650
FORM A PROTECTION LAYER ON THE SECOND ELECTRODE AND THE PIEZOELECTRIC LAYER
660
FORM A FIRST CONNECTION PART AND A SECOND CONNECTION PART
670
END

FIG. 6

ACOUSTIC RESONATOR AND METHOD OF MANUFACTURING THE SAME

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit under 35 USC 119(a) of Korean Patent Application No. 10-2015-0181490 filed on Dec. 18, 2015 in the Korean Intellectual Property Office, the entire disclosure of which is incorporated herein by reference for all purposes.

BACKGROUND

1. Field

The following description relates to an acoustic resonator and a method of manufacturing the same.

2. Description of Related Art

With the recent trend to miniaturize wireless communications devices, efforts have been made to also reduce radio frequency components that are used in the wireless communications devices. Film bulk acoustic resonators (FBAR) manufactured using semiconductor thin film wafer technology are an example thereof.

A film bulk acoustic resonator refers to a resonator implemented with a thin film element that resonates. The thin film element is generally obtained by depositing a piezoelectric dielectric material on a semiconductor substrate, such as a silicon wafer, in order to utilize the piezoelectric characteristics of a piezoelectric dielectric material.

Film bulk acoustic resonators have a wide range of application. For example, film bulk acoustic resonators are used as small and light weight filters for devices such as mobile communications devices, chemical and biological devices, and the like, and as an oscillator, a resonance element, an acoustic resonance mass sensor, and the like.

SUMMARY

This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter.

In one general aspect, an acoustic resonator includes a resonating part including a first electrode, a second electrode, and a piezoelectric layer disposed between the first electrode and the second electrode, and a plurality of seed layers disposed on one side of the resonating part.

The general aspect of the acoustic resonator may further include a substrate disposed on the opposite side of the resonating part from the plurality of seed layers.

An air gap may be disposed between the substrate and the plurality of seed layers.

The resonating part may further include a protection layer.

A membrane may be interposed between the substrate and the plurality of seed layers, and an air gap may be disposed between the substrate and the membrane.

The membrane may include a plurality of membrane layers, and at least one membrane layer of the plurality of membrane layers may be an etching stopper.

The plurality of seed layers may include a first seed layer and a second seed layer. The first seed layer may include a material having the same crystalline system as a material of the piezoelectric layer. The second seed layer may include a material having the same unit cell geometry as a material of the first seed layer.

A thickness of the first seed layer or the second seed layer may be within a range of 10 Å to 1,000 Å.

The piezoelectric layer, the first seed layer, and the second seed layer may each include a material having a hexagonal crystal system.

The piezoelectric layer may include aluminum nitride or doped aluminum nitride. The first electrode may include molybdenum. The first seed layer may include aluminum nitride. The second seed layer may include titanium.

An upper surface of the first seed layer may correspond to a (002) plane of hexagonal crystal lattice.

In another general aspect, a method of manufacturing an acoustic resonator includes forming a sacrificial layer on a substrate, forming a plurality of seed layers on the substrate or the sacrificial layer, forming a first electrode on the plurality of seed layers, forming a piezoelectric layer on the first electrode, and forming a second electrode on the piezoelectric layer.

The general aspect of the method may further include, before the forming of the plurality of seed layers, forming a membrane on the substrate or the sacrificial layer.

In the forming of the plurality of seed layers, at least one seed layer of the plurality of seed layers may be grown in only a stacking direction.

The general aspect of the method may further include forming a protection layer on the second electrode and the piezoelectric layer.

The general aspect of the method may further include forming an air gap by removing the sacrificial layer.

In another general aspect, a method of manufacturing an acoustic resonator involves depositing a first electrode on a plurality of seed layers, and depositing a piezoelectric layer on the first electrode, in which the plurality of seed layers includes a first seed layer and a second seed layer, and the first seed layer and the second seed layer include materials having a same unit cell geometry.

The plurality of seed layers may be obtained by depositing the first seed layer on the second seed layer.

The first seed layer may be deposited on a hexagonal (002) plane of a material forming the second seed layer.

The first seed layer or the second seed layer may include a material that belongs to the same crystalline system as a material forming the piezoelectric layer.

The first seed layer may be grown without a polycrystalline growth region on the first seed layer.

An upper surface of the second seed layer may correspond to a (002) plane of titanium or a (002) plane of aluminum nitride.

Other features and aspects will be apparent from the following detailed description, the drawings, and the claims.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a cross-sectional view of an example of an acoustic resonator.

FIG. **2** is an enlarged cross-sectional view illustrating an example of a resonating portion of an acoustic resonator illustrated in FIG. **1**.

FIG. **3** is a cross-sectional view of another example of an acoustic resonator.

FIG. **4** is an enlarged cross-sectional view illustrating an example of a resonating portion of an acoustic resonator illustrated in FIG. **3**.

FIG. **5** is an enlarged cross-sectional view illustrating another example of an acoustic resonator.

FIG. **6** is a flowchart illustrating an example of a method of manufacturing an acoustic resonator.

Throughout the drawings and the detailed description, the same reference numerals refer to the same elements. The drawings may not be to scale, and the relative size, proportions, and depiction of elements in the drawings may be exaggerated for clarity, illustration, and convenience.

DETAILED DESCRIPTION

The following detailed description is provided to assist the reader in gaining a comprehensive understanding of the methods, apparatuses, and/or systems described herein. However, various changes, modifications, and equivalents of the methods, apparatuses, and/or systems described herein will be apparent to one of ordinary skill in the art. The sequences of operations described herein are merely examples, and are not limited to those set forth herein, but may be changed as will be apparent to one of ordinary skill in the art, with the exception of operations necessarily occurring in a certain order. Also, descriptions of functions and constructions that are well known to one of ordinary skill in the art may be omitted for increased clarity and conciseness.

The features described herein may be embodied in different forms, and are not to be construed as being limited to the examples described herein. Rather, the examples described herein have been provided so that this disclosure will be thorough and complete, and will convey the full scope of the disclosure to one of ordinary skill in the art.

As noted above, acoustic resonators have a wide range of application. However, various structural shapes and functions for increasing characteristics and performances of acoustic resonators, such as a film bulk acoustic resonators (FBAR), are being researched. For example, a demand exists for modifications to the structure, the material or the manufacturing method of producing film bulk acoustic resonators that may secure various frequencies and bands.

In order to increase a data transfer amount and a data transfer rate, an acoustic resonator such as a film bulk acoustic resonator (FBAR), for example, may need to have a wide bandwidth.

In order to secure the wide bandwidth as described above, an electro-mechanical coupling coefficient (kt2) value of the acoustic resonator may need to be increased.

However, because the kt2 value of the acoustic resonator typically exists in a trade-off relationship with a quality factor (QF), a technology that can increase the kt2 value without sacrificing the quality factor is demanded.

As a method of improving the kt2 value, a method of increasing crystallinity of a piezoelectric layer itself has been researched.

According to an aspect of the present description, an acoustic resonator capable of increasing the overall performance by increasing crystallinity of a piezoelectric material is suggested. According to another aspect, in order to improve the kt2 value by securing crystallinity of the piezoelectric layer, a method in which a plurality of seed layers are added to bottoms of electrodes is suggested.

According to an aspect, an acoustic resonator may include: a resonating part including a first electrode, a second electrode, and a piezoelectric layer disposed between the first electrode and the second electrode; and a plurality of seed layers disposed on one side of the resonating part, whereby crystallinity of the piezoelectric layer may be secured and an electro-mechanical coupling coefficient (kt2) value of the acoustic resonator may be improved.

According to another aspect, a method of manufacturing an acoustic resonator may include: forming a sacrificial layer on a substrate; forming a plurality of seed layers on the substrate or the sacrificial layer; forming a first electrode on the plurality of seed layers; forming a piezoelectric layer on the first electrode; and forming a second electrode on the piezoelectric layer, whereby an acoustic resonator having a high kt2 value may be provided by a simple process

FIG. **1** illustrates a cross-sectional view of an example of an acoustic resonator, and FIG. **2** illustrates an enlarged cross-sectional view illustrating an example of a resonating portion of the acoustic resonator illustrated in FIG. **1**.

Referring to FIGS. **1** and **2**, an acoustic resonator **100** includes a resonating part **120** including a first electrode **121**, a second electrode **122**, and a piezoelectric layer **123** disposed between the first electrode and the second electrode; and a plurality of seed layers **140** disposed on one side of the resonating part **120**.

Further, the acoustic resonator **100** includes a substrate **110** disposed on an opposite side of the plurality of seed layers **140** from the resonating part **120**.

The substrate **110** may be formed in a silicon substrate or a silicon on insulator (SOI) type substrate.

In this example, an air gap **130** is formed between the substrate **110** and the plurality of seed layers **140**, and at least a portion of the plurality of seed layers is disposed to be spaced apart from the substrate **110** by the air gap **130**.

By forming the air gap **130** between the plurality of seed layers **140** and the substrate **110**, an acoustic wave generated from the piezoelectric layer **123** may not be affected by the substrate.

Further, the reflective characteristics of the acoustic wave generated from the resonating part **120** may be improved by the air gap **130**.

Because the air gap **130**, which is an empty space, has an impedance that is close to infinity, the acoustic wave may remain in the resonating part **120** while not being lost by the air gap.

Therefore, the loss of the acoustic wave in a longitudinal direction may be significantly reduced by the air gap **130**. As a result, a quality factor (QF) of the resonating part **120** may be improved.

The resonating part **120** includes the first electrode **121**, the second electrode **122**, and the piezoelectric layer **123** as described above. The resonating part **120** may be formed by sequentially laminating the first electrode **121**, the piezoelectric layer **123**, the second electrode **122** from below.

When the layers are formed in this order, the piezoelectric layer **123** is disposed between the first electrode **121** and the second electrode **122**.

The resonating part **120** may make the piezoelectric layer **123** resonate in response to electrical signals applied to the first electrode **121** and the second electrode **122** to generate a resonance frequency and an anti-resonance frequency.

The first electrode **121** and the second electrode **122** may be formed of a metal such as gold, molybdenum, ruthenium, aluminum, platinum, titanium, tungsten, palladium, chrome, nickel, iridium, or the like.

The resonating part **120** may use the acoustic wave of the piezoelectric layer **123**. For example, in response to signals being applied to the first electrode **121** and the second electrode **122**, mechanical vibration may occur in a thickness direction of the piezoelectric layer **123** to generate the acoustic wave.

The piezoelectric layer **123** may be formed of a piezoelectric material such as zinc oxide (ZnO), aluminum nitride (AlN), silicon dioxide (SiO_2), doped zinc oxide (e.g., W—ZnO), doped aluminum nitride (e.g., Sc—AlN, MgZr—AlN, Cr—AlN, Er—AlN, Y—AlN), or the like.

A resonance phenomenon of the piezoelectric layer **123** may occur in response to a half of a wavelength of the applied signal matching a thickness of the piezoelectric layer.

Because the electrical impedance sharply changes in response to the occurrence of resonance phenomenon, the acoustic resonator according to this embodiment may be used as a filter capable of selecting a frequency.

The resonance frequency may be determined by the thickness of the piezoelectric layer **123**, the inherent acoustic wave velocity of the piezoelectric layer **123**, the first electrode **121** and the second electrode **122** that surround the piezoelectric layer **123**, and the like.

In general, in response to the thickness of the piezoelectric layer **123** being reduced, the resonance frequency is increased.

Further, because the piezoelectric layer **123** is disposed only in the resonating part **120**, a phenomenon in which the acoustic wave generated by the piezoelectric layer is leaked externally from the resonating part may be significantly reduced.

In this example, the resonating part **120** further includes a protection layer **124**.

The protection layer **124** covers the second electrode **122** to prevent the second electrode **122** from being exposed to an external environment. However, the present description is not limited thereto.

In this example, the first electrode **121** and the second electrode **122** extend to an outer side of the piezoelectric layer **123**, and a first connection part **180** and a second connection part **190** are each connected to the extended portion.

The first connection part **180** and the second connection part **190** may be provided to confirm characteristics of the resonator and the filter and perform a required frequency trimming, but are not limited thereto.

The plurality of seed layers **140** are disposed on one side of the resonating part **120**, that is, below the first electrode **121**.

The plurality of seed layers **140** includes a first seed layer **141** and a second seed layer **142**, and the first seed layer and the second seed layer may be obtained by being sputtered on a planarized substrate **110** or a sacrificial layer (not illustrated).

The first seed layer **141** may be manufactured using aluminum nitride (AlN), doped aluminum nitride (e.g., Sc—AlN, MgZr—AlN, Cr—AlN, Er—AlN, Y—AlN), or other similar crystalline materials, such as aluminum oxynitride (AlON), silicon dioxide (SiO_2), silicon nitride (Si_3N_4), silicon carbide (SiC), and the like.

In an example, the first seed layer **141** is formed of aluminum nitride (AlN). The second seed layer **142** is formed of a material having the same crystalline system or Bravais lattice system as the material forming the first seed layer **141**. For example, aluminum nitride (AlN) has a hexagonal crystal system. Thus, in the event that the first seed layer **141** is formed of aluminum nitride (AlN), the second seed layer **142** may be formed of a metal of a hexagonal system having unit cells of the same geometry, such as magnesium (Mg), titanium (Ti), zinc (Zn), and the like.

FIGS. **1** and **2** illustrate an example in which the first seed layer **141** is stacked on the second seed layer **142**, but the order of stacking the first and second seed layers is not limited thereto. On the contrary, the second seed layer may be stacked on the first seed layer.

In this example, at least one of the seed layers is formed of a piezoelectric material so as not to serve as an electrode and rather to serve as a piezoelectric layer, thereby affecting the piezoelectric characteristics of the piezoelectric layer **123**.

As a result, in the event that a film thickness of the seed layers becomes too thick, an influence on piezoelectric characteristics of the piezoelectric layer may be increased. Thus, according to one example, a thickness of the first seed layer **141** may be set within a range of about 10 Å to 1,000 Å so that the influence on piezoelectric characteristics is not increased more than necessary.

Further, the second seed layer **142** formed of a metal that belongs to the hexagonal crystal system or having the same crystal lattice structure such as titanium, or the like, may need to be grown in only a (001) direction, that is, a stacking direction. However, if a thickness of the second seed layer **142** is grown to be 1,000 Å or more, the second seed layer **142** may also be grown in a (010) direction in addition to a (001) direction, thereby increasing a lattice mismatch with the first seed layer **141**.

Eventually, because a growth in a (010) direction causes deterioration in crystallinity of the first electrode **121** and the piezoelectric layer **123** grown on the second seed layer **142**, according to one example, the thickness of the second seed layer **142** is also set to 1,000 Å or less in which the second seed layer **142** is grown in only a (001) direction, that is, the stacking direction.

In order to increase the crystallinity of the piezoelectric layer **123**, the crystallinity of the first electrode **121** disposed below the piezoelectric layer **123** may need to be secured. To this end, according to one example, a plurality of seed layers **140** is used below the first electrode.

For example, in the event that a piezoelectric layer **123** is formed of aluminum nitride (AlN) and the first electrode **121** is formed of molybdenum, a thin film of the piezoelectric layer formed of aluminum nitride may initially show polycrystalline growth characteristics, and may then be aligned in a (001) direction in which the growth speed is the fastest.

In the event that the first electrode **121** formed of molybdenum is grown without using any seed layers, the crystallinity of the piezoelectric layer **123** formed of aluminum nitride that is deposited on the first electrode **121** may also deteriorate due to the defects in the crystalline structure of the molybdenum first electrode **121**.

However, in an example, by utilizing a first seed layer **141** formed of aluminum nitride, an aluminum nitride seed starts to grow in a (001) direction, that is, the stacking direction, there by securing a higher crystallinity of the first electrode **121** formed of molybdenum, and a higher crystallinity of the piezoelectric layer **123** formed of aluminum nitride disposed on the first electrode **121**.

As such, in this example, the piezoelectric layer **123** exhibits excellent crystallinity, and the kt2 value of the acoustic resonator **100** is increased.

Meanwhile, because aluminum nitride (002) and molybdenum (110) have a very large lattice mismatch of 12.45%, a method of increasing piezoelectric characteristics by increasing the thickness of the piezoelectric layer formed of aluminum nitride may be applied; however, due to a size limit imposed on the acoustic resonators, there exists a limit in increasing the piezoelectric characteristics by using the method of increasing the thickness of the piezoelectric layer until the polycrystalline growth gradually shifts to a single-crystal growth.

However, because a lattice mismatch between molybdenum (110) and titanium (002) is only 7.64%, an excellent crystallinity may be secured for a molybdenum layer by juxtaposing a titanium seed layer.

In an example, a molybdenum layer may be aligned in a (110) crystalline plane direction. An excellent crystallinity for an aluminum nitride layer may be obtained by forming the aluminum nitride layer on a molybdenum layer exposing the (110) plane.

According to an X-ray diffraction test, it may be seen that when titanium is grown in only a (001) direction, that is, the stacking direction, and molybdenum and aluminum nitride are deposited on titanium, aluminum nitride is grown in only a (001) direction and molybdenum is grown in only a (110) direction, similar to when molybdenum and aluminum nitride are deposited on the aluminum nitride seed, thereby securing improved crystallinity of the piezoelectric layer as compared to the case in which only the aluminum nitride seed is used.

Further, it may be seen that the lattice mismatch between aluminum nitride (002) and titanium (002), which is 5.49%, is lower than the lattice mismatch between molybdenum (110) and titanium (002), which is 7.64%.

Further, it may be seen that because aluminum nitride and titanium have the same hexagonal system, excellent crystallinity may be secured when two materials are stacked on each other.

Therefore, according to an example, in order to improve the kt2 value by securing crystallinity of the piezoelectric layer **123**, the second seed layer **142** formed of, for example, titanium, or the like, having a low lattice mismatch, that is, the plurality of seed layers, may be disposed below the first seed layer **141** formed of, for example, aluminum nitride, or the like.

According to one example, a second seed layer **142** formed of titanium having the low lattice mismatch is employed below the first seed layer **141** formed of aluminum nitride. Because titanium is grown in a (001) direction, that is, the stacking direction, and titanium (002) and aluminum nitride (002) have the low lattice mismatch, the first seed layer formed of aluminum nitride may be directly grown in a (001) direction, that is, the stacking direction without an initial polycrystalline growth.

As a result, high crystallinity of the first seed layer **141** formed of aluminum nitride (002) may be secured, and crystallinity of the first electrode **121** formed of molybdenum (110) and the piezoelectric layer **123** formed of aluminum nitride (002) grown on the first seed layer **141** may be improved. As a result, a high kt2 value may be obtained without increasing loss in the acoustic wave.

FIG. **6** illustrates an example of a method of manufacturing an acoustic resonator.

First, a sacrificial layer is formed on a substrate **110** in **610**. As a material for the sacrificial layer, silicon dioxide, polysilicon, polymer, or the like may be used.

The sacrificial layer may be removed later by an etching process to form an air gap **130**. The shape of the sacrificial layer may conform to the shape of the air gap **130** to be formed later.

Next, a plurality of seed layers **140** may be sequentially formed on the substrate **110** and the sacrificial layer in **620**. A technology and a process of manufacturing the seed layers widely known in the art, such as a sputtering technology, may be used to manufacture the seed layers.

By properly controlling process conditions of the sputtering that is performed such as, for example, a temperature, the degree of a vacuum, strength of power, an amount of injected gas, and the like, the plurality of seed layers **140** may be grown in only a (001) direction, that is, the stacking direction.

As such, in an example in which most of the plurality of seed layers are oriented in a desired direction, that is, a (001) direction, when the piezoelectric layer **123** is formed on the plurality of seed layers **140** as described below, the piezoelectric layer may succeed a crystal structure of the seed layers **140** to be oriented in the same crystal structure as the seed layers **140**.

According to one example, the first seed layer **141** may be formed of aluminum nitride (AlN), but is not limited thereto. For example, various materials such as silicon dioxide (SiO_2), silicon nitride (Si_3N_4), silicon carbide (SiC), aluminum oxynitride (AlON), and the like may be used.

Further, the second seed layer **142** may be formed of titanium (Ti), but is not limited thereto. For example, a metal such as magnesium, zinc, or the like may be used.

In an example of a filter that includes a plurality of resonators, a second seed layer **142** may need to be selectively formed in only the predetermined resonator that requires a high kt2 value. Thus, the second seed layer **142** may be left on only a predetermined portion of the filter by performing a patterning after forming the second seed layer using titanium by the sputtering, and the following processes may be performed.

According to an example, the second seed layer **142** may be formed of a material having a hexagonal close packed structure such as titanium (Ti), magnesium (Mg), zinc (Zn), or the like, before the first seed layer **141**. For example, a titanium seed layer having a thickness of 10 to 1000 Å may be formed directly on a Si substrate. The crystal orientation of the second seed layer comprised of titanium deposited by a sputtering method may be controlled in order to expose substantially a (002) plane of its hexagonal lattice. When the thickness of the titanium seed layer exceeds 1000 Å, the growth along a (010) plane of the lattice increases, thereby increasing dislocation.

On an upper surface corresponding to a (002) plane of titanium layer, the first seed layer **141** may be grown. The first seed layer **141** may be an aluminum nitride (AlN) layer, but the present description is not limited thereto. For example, various materials such as silicon dioxide (SiO_2), silicon nitride (Si_3N_4), silicon carbide (SiC), aluminum oxynitride (AlON), and the like may be used.

A first seed layer **141** comprised of aluminum nitride (AlN) may be grown with high crystallinity on a (002) plane of a titanium layer because the lattice mismatch is low. The aluminum nitride (AlN) seed layer may be deposited by a sputtering method to expose a (002) plane of its hexagonal lattice. By forming the second seed layer **141** of titanium (002) prior to forming the first seed layer **141** of aluminum nitride (002), it is possible to prevent an initial polycrystalline growth of aluminum nitride on a silicon substrate. Accordingly, the plurality of seed layers **140** makes it possible to secure high crystallinity for subsequent layers deposited thereon.

Thereafter, the first electrode **121** and the piezoelectric layer **123** are sequentially formed on the plurality of seed layers **140**.

In **630**, the first electrode **121** is formed. The first electrode **121** may be formed by depositing a conductive layer on the seed layers **140**. Similarly, in **640**, the piezoelectric layer **123** may be formed by depositing a piezoelectric material on the first electrode **121**.

In the illustrated embodiment, the first electrode **121** may be formed of a molybdenum (Mo) material, but is not limited thereto. For example, various metals such as gold, ruthenium, aluminum, platinum, titanium, tungsten, palladium, chrome, nickel, iridium, and the like may be used.

According to one example, a first electrode **121** composed of molybdenum (Mo) is deposited on a (002) plane of a first seed layer **141** formed of aluminum nitride (AlN), the first seed layer **141** deposited on a (002) plane of a second seed layer **142** formed of titanium (Ti), For instance, the first electrode **121** of molybdenum (110) may be grown on a first seed layer **142** formed of a (002) oriented aluminum nitride layer.

Further, the piezoelectric layer **123** may be formed of aluminum nitride (AlN), but is not limited thereto. For example, various piezoelectric materials such as zinc oxide (ZnO), silicon dioxide (SiO_2), doped zinc oxide (e.g., W—ZnO), doped aluminum nitride (e.g., Sc—AlN, MgZr—AlN, Cr—AlN, Er—AlN, Y—AlN), and the like may be used.

According to one example, a piezoelectric layer **123** formed of aluminum nitride (AlN) may be formed on a first electrode **121** of Mo (110) formed on a first seed layer **141** of AlN (002) and a second seed layer **142** of Ti (002). A high crystallinity piezoelectric layer **123** may be obtained by controlling the crystalline orientation at the interface between the first seed layer **141** and the second seed layer **142**, the first seed layer **141** and the first electrode **121**, and the first electrode **121** and the piezoelectric layer **123**.

The first electrode **121** and the piezoelectric layer **123** may be formed in a predetermined pattern by depositing a photoresist on the conductive layer or the piezoelectric layer, performing the patterning using a photolithography process, and then removing unnecessary portions using the patterned photoresist as a mask.

Thereby, the piezoelectric layer **123** may be left on only the first electrode **121**. As a result, the first electrode may be left to further protrude around the piezoelectric layer.

Next, the second electrode **122** is formed in **650**.

The second electrode **122** may be formed in a predetermined pattern by forming the conductive layer on the piezoelectric layer **123** and the first electrode **121**, depositing the photoresist on the conductive layer, performing the patterning using the photolithography process, and then removing unnecessary portions using the patterned photoresist as the mask.

According to one example, the second electrode **122** may be formed of ruthenium (Ru), but is not limited thereto. For example, various metals such as gold, molybdenum, aluminum, platinum, titanium, tungsten, palladium, chrome, nickel, iridium, and the like may be used.

Next, the protection layer **124** is formed on the second electrode **122** and the piezoelectric layer **123** in **660**.

The protection layer **124** may be formed of an insulating material. Examples of the insulating material include silicon oxide based materials, silicon nitride based materials, and aluminum nitride based materials.

Thereafter, the connection parts **180** and **190** are formed in **670**. The connection parts **180** and **190** may be used for a frequency trimming.

The first connection part **180** and the second connection part **190** may penetrate through the protection layer **124** to be bonded to the first electrode **121** and the second electrode **122**, respectively.

The first connection part **180** may be formed by partially removing the protection layer **124** by the etching to form a hole, externally exposing the first electrode **121**, and then depositing gold (Au), copper (Cu), or the like on the first electrode.

Similarly, the second connection part **190** may also be formed by partially removing the protection layer **124** by the etching to form the hole, externally exposing the second electrode **122**, and then depositing gold (Au), copper (Cu), or the like on the second electrode.

After confirming characteristics of the resonating part **120** or the filter and performing a frequency trimming as desirable using the connection parts **180** and **190**, the air gap **130** may be formed.

The air gap **130** may be formed by removing the sacrificial layer as described above. As a result, the resonating part **120** may be completed.

Here, the sacrificial layer may be removed by a dry etching, but is not limited thereto.

For example, the sacrificial layer may be formed of polysilicon. Such a sacrificial layer may be removed by dry etching gas such as xenon difluoride (XeF_2).

Meanwhile, the acoustic resonator and the method of manufacturing the same according to the present disclosure are not limited to the above-mentioned embodiments, and may be variously modified.

FIG. **3** illustrates a cross-sectional view of another example of an acoustic resonator, and FIG. **4** illustrates an enlarged cross-sectional view of a main part of the acoustic resonator illustrated in FIG. **3**.

Referring to FIGS. **3** and **4**, an acoustic resonator **200** includes a resonating part **120** including a first electrode **121**, a second electrode **122**, and a piezoelectric layer **123** disposed between the first electrode and the second electrode; a plurality of seed layers **140** disposed on one side of the resonating part; and a membrane **150** disposed on the opposite side of the resonating part from the seed layers.

The remaining components of the acoustic resonator illustrated in FIG. **3** are the same as those described above with reference to FIGS. **1** and **2**, except that the membrane **150** is disposed below the plurality of seed layers **140**.

Thus, in describing the acoustic resonator **200** according to another example, the same components as those of the acoustic resonator **100** are denoted by like reference numerals.

Referring to FIGS. **3** and **4**, the acoustic resonator **200** further includes the substrate **110** disposed on an opposite side of the plurality of seed layers **140** from the resonating part **120**. In addition, the membrane **150** is interposed between the plurality of seed layers **140** and the substrate **110**.

The substrate **110** may be formed in a silicon substrate or a silicon on insulator (SOI) type substrate.

The air gap **130** is formed between the substrate **110** and the membrane **150**, and at least a portion of the membrane may be disposed to be spaced apart from the substrate by the air gap.

Further, because the resonating part **120** is formed on the membrane **150**, the resonating part may also be spaced apart from the substrate **110** by the air gap **130**.

By forming the air gap **130** between the substrate **110** and the membrane **150**, an acoustic wave generated from the piezoelectric layer **123** may not be affected by the substrate.

Further, reflective characteristics of the acoustic wave generated from the resonating part **120** may be improved by the air gap **130**.

Because the air gap **130**, which is an empty space, has impedance that is close to infinity, the acoustic wave may remain in the resonating part **120** while not being lost by the air gap **130**.

Therefore, loss of the acoustic wave in a longitudinal direction may be significantly reduced by the air gap **130**. As a result, a quality factor (QF) of the resonating part **120** may be improved.

In this example, the membrane **150** is positioned on the air gap **130** to maintain a shape of the air gap **130** and to provide structural support to the resonating part **120**.

The membrane **150** may be formed of silicon dioxide (SiO_2), or the like.

As described below, in an example in which the air gap **130** is formed by etching the sacrificial layer, the membrane may be formed of a plurality of membrane layers so that the membrane **150** may serve as an etching stopper.

For example, referring to FIG. **5**, the membrane **150** includes a first membrane layer **151** formed of, for example, silicon dioxide (SiO_2), and a second membrane layer **152** formed of, for example, silicon nitride (SiN_x) and formed on the first membrane layer.

Of course, a stop layer **160** serving as the etching stopper may also be formed on the substrate to protect the substrate **110**, and the stop layer may include silicon oxide (SiO_x), silicon nitride (SiN_x), or the like.

The resonating part **120** includes the first electrode **121**, the piezoelectric layer **123**, and the second electrode **122**, as described above, and the resonating part **120** may be obtained by sequentially laminating the first electrode, the piezoelectric layer, and the second electrode from below.

The resonating part **120** may make the piezoelectric layer **123** resonate in response to electrical signals applied to the first electrode **121** and the second electrode **122** to generate a resonance frequency and an anti-resonance frequency.

The first electrode **121** and the second electrode **122** may be formed of a metal such as gold, molybdenum, ruthenium, aluminum, platinum, titanium, tungsten, palladium, chrome, nickel, iridium, or the like.

The resonating part **120** may use the acoustic wave of the piezoelectric layer **123**. For example, in response to signals being applied to the first electrode **121** and the second electrode **122**, mechanical vibration may occur in a thickness direction of the piezoelectric layer **123** to generate the acoustic wave.

The piezoelectric layer **123** may be formed of a piezoelectric material such as zinc oxide (ZnO), aluminum nitride (AlN), silicon dioxide (SiO_2), doped zinc oxide (e.g., W—ZnO), doped aluminum nitride (e.g., Sc—AlN, MgZr—AlN, Cr—AlN, Er—AlN, Y—AlN), or the like.

In the illustrated example, the resonating part **120** further includes the protection layer **124**.

The protection layer **124** covers the second electrode **122** to prevent the second electrode from being exposed to an external environment.

The first electrode **121** and the second electrode **122** extend to an outer side of the piezoelectric layer **123**, and the first connection part **180** and the second connection part **190** are each connected to the extended portion.

The first connection part **180** and the second connection part **190** may be provided to confirm characteristics of the resonator and the filter and to perform a required frequency trimming, but are not limited thereto.

The plurality of seed layers **140** are disposed between the resonating part **120** and the membrane **150**, that is, below the first electrode **121** and on the membrane **150**.

The plurality of seed layers **140** includes the first seed layer **141** and the second seed layer **142**, and the first seed layer and the second seed layer may be deposited by being sputtered on a planarized substrate **110** or a sacrificial layer (not illustrated).

The first seed layer **141** may be manufactured using aluminum nitride (AlN), doped aluminum nitride (e.g., Sc—AlN, MgZr—AlN, Cr—AlN, Er—AlN, Y—AlN), or other similar crystalline materials, such as aluminum oxynitride (AlON), silicon dioxide (SiO_2), silicon nitride (Si_3N_4), silicon carbide (SiC), and the like.

In an example, the first seed layer is formed of aluminum nitride (AlN), and the second seed layer **142** is formed of a material having the same crystalline lattice structure with the first seed layer **141**. For example, the second seed layer **142** may be formed of a metal of a hexagonal lattice system having the same unit cell geometry, such as magnesium (Mg), titanium (Ti), zinc (Zn), and the like.

FIGS. **3** through **5** illustrate examples of acoustic resonators in which the first seed layer **141** is stacked on the second seed layer **142**, but the order of stacking the first and second seed layers is not limited thereto. On the contrary, the second seed layer may be stacked on the first seed layer.

In these examples, at least one of the seed layers **140** is formed of a piezoelectric material so as not to serve as an electrode and rather to serve as a piezoelectric layer, thereby affecting the piezoelectric characteristics of the piezoelectric layer **123**.

In the event that a film thickness of the seed layers becomes too thick, an influence on piezoelectric characteristics of the piezoelectric layer **123** may be increased. Thus, according to these examples, a thickness of the first seed layer **141** is set within the range of about 10 Å to 1,000 Å so that the influence on piezoelectric characteristics is not increased more than desirable.

Further, the second seed layer **142** formed of the metal of the hexagonal system such as titanium, or the like, may need to be grown in only a (001) direction, that is, a stacking direction. However, in the event that a thickness of the second seed layer **142** is grown to be 1,000 Å or more, the second seed layer **142** may also be grown in a (010) direction in addition to a (001) direction, thereby increasing a lattice mismatch with the first seed layer **141**.

Because growing a thick layer eventually causes a deterioration in the crystallinity of the first electrode **121** and the piezoelectric layer **123** grown on the second seed layer **142**, according to one example, the thickness of the second seed layer **142** is set to be 1,000 Å or less such that the second seed layer **142** is grown in only a (001) direction, that is, the stacking direction.

In order to increase the crystallinity of the piezoelectric layer **123**, the crystallinity of the first electrode **121** disposed below the piezoelectric layer **123** may need to be secured. To this end, according to one example, the plurality of seed layers **140** are used below the first electrode.

In this example, in order to improve the kt2 value by securing the crystallinity of the piezoelectric layer **123**, the second seed layer **142** formed of, for example, titanium, or the like, having a low lattice mismatch, that is, the plurality of seed layers, may be disposed below the first seed layer formed of, for example, aluminum nitride, or the like.

According to one example, a second seed layer **142** formed of titanium is employed below a first seed layer **141** formed of aluminum nitride. Because titanium is grown in a (001) direction, that is, the stacking direction, and titanium and aluminum nitride have a low lattice mismatch, the first seed layer formed of aluminum nitride may be directly grown in a (001) direction, that is, the stacking direction without an initial polycrystalline growth.

As a result, a high crystallinity is secured for the first seed layer **141** formed of aluminum nitride, and the crystallinity of the first electrode **121** formed of molybdenum and the piezoelectric layer **123** formed of aluminum nitride grown on the first seed layer **141** is improved. Thus, a high kt2 value may be obtained without increasing loss in the acoustic wave.

Hereinafter, another example of a method of manufacturing an acoustic resonator will be described.

First, a sacrificial layer (not illustrated) may be formed on the substrate **110**, as in **610** of FIG. **6**. As a material for the sacrificial layer, silicon dioxide, polysilicon, polymer, or the like may be used.

The sacrificial layer may be removed later by an etching process to form the air gap **130**.

Next, a membrane **150** may be formed on the substrate **110**. The membrane **150** may be deposited on the substrate **110** and the sacrificial layer.

As a method of forming the membrane **150**, a proper method may be selected and used among deposition methods such as a chemical vapor deposition (CVD) method, a sputtering method, and the like, depending on a material that forms the membrane **150**.

Further, according to one example, as the membrane, a first membrane layer **151** formed of, for example, silicon dioxide (SiO_2) may be formed, and a second membrane layer **152** formed of, for example, silicon nitride (SiN_x) may be formed on the first membrane layer.

In addition, a plurality of seed layers **140** may be sequentially formed on the membrane **150**. A technology or process of manufacturing the seed layers widely known in the art, such as a sputtering technology, may be used to manufacture the seed layers.

According to one example, by properly controlling the process conditions of the sputtering, such as a temperature, the degree of a vacuum, strength of power, an amount of injected gas, and the like, the plurality of the seed layers **140** may be grown in only a (001) direction, that is, the stacking direction.

As such, in an example in which most of the plurality of seed layers are oriented in a desired direction, that is, a (001) direction, when the piezoelectric layer **123** is formed on the plurality of seed layers **140** as described below, the piezoelectric layer may succeed a crystal structure of the seed layers **140** to be oriented in the same crystal structure and orientation as the seed layers **140**.

According to one example, the first seed layer **141** may be formed of aluminum nitride (AlN), but is not limited thereto. For example, various materials such as silicon dioxide (SiO_2), silicon nitride (Si_3N_4), silicon carbide (SiC), aluminum oxynitride (AlON), and the like may be used.

Further, according to another example, the second seed layer **142** may be formed of titanium (Ti), but is not limited thereto. For example, a metal such as magnesium (Mg), zinc (Zn), or the like may be used.

Thereafter, the first electrode **121** and the piezoelectric layer **123** may be sequentially formed on a plurality of seed layers **140**.

The first electrode **121** may be formed by depositing a conductive layer on the seed layers **140**. Similarly, the piezoelectric layer **123** may be formed by depositing a piezoelectric material on the first electrode.

According to another example, the first electrode **121** may be formed of a molybdenum (Mo) material, but is not limited thereto. For example, various metals such as gold, ruthenium, aluminum, platinum, titanium, tungsten, palladium, chrome, nickel, iridium, and the like may be used.

Further, according to one example, the piezoelectric layer **123** may be formed of aluminum nitride (AlN), but is not limited thereto. For example, various piezoelectric materials such as zinc oxide (ZnO), silicon dioxide (SiO_2), doped zinc oxide (e.g., W—ZnO), doped aluminum nitride (e.g., Sc—AlN, MgZr—AlN, Cr—AlN, Er—AlN, Y—AlN), and the like may be used.

In this example, the first electrode **121** and the piezoelectric layer **123** may be formed in a predetermined pattern by depositing a photoresist on the conductive layer or the piezoelectric layer, performing the patterning using a photolithography process, and then removing unnecessary portions using the patterned photoresist as a mask.

Thereby, the piezoelectric layer **123** may be left on only the first electrode **121**. As a result, the first electrode may be left to further protrude around the piezoelectric layer **123**.

Next, the second electrode **122** may be formed.

The second electrode **122** may be formed in a predetermined pattern by forming the conductive layer on the piezoelectric layer **123** and the first electrode **121**, depositing the photoresist on the conductive layer, performing the patterning using the photolithography process, and then removing unnecessary portions using the patterned photoresist as the mask.

According to another example, the second electrode **122** may be formed of ruthenium (Ru), but is not limited thereto. For example, various metals such as gold, molybdenum, aluminum, platinum, titanium, tungsten, palladium, chrome, nickel, iridium, and the like may be used.

The protection layer **124** may also be formed on the second electrode **122** and the piezoelectric layer **123**.

Further, the first connection part **180** and the second connection part **190** may penetrate through the protection layer **124** to be bonded to the first electrode **121** and the second electrode **122**, respectively.

After confirming characteristics of the resonating part **120** or the filter and performing any necessary frequency trimming using the connection parts **180** and **190**, the air gap **130** may be formed.

The air gap **130** may be formed by removing the sacrificial layer as described above. As a result, the resonating part **120** according to another example may be completed.

In this example, the sacrificial layer may be removed by a dry etching, but the present description is not limited thereto.

According to one example, the sacrificial layer is formed of polysilicon.

Such a sacrificial layer may be removed by using a dry etching gas such as xenon difluoride (XeF_2).

When the air gap **130** is formed by etching the sacrificial layer, in the event that the membrane **150** is formed of a plurality of membrane layers, a second membrane layer **152** formed on a first membrane layer **151** may serve as an etching stopper to protect the plurality of seed layers **140** formed on the second membrane layer **152** from being etched.

The first membrane layer **151** may be formed of, for example, silicon dioxide (SiO_2), or the like, and the second membrane layer **152** may be formed of, for example, silicon nitride (SiN_x), or the like. However, the present description are not limited thereto.

Meanwhile, the acoustic resonator and the method of manufacturing the same according to the present description are not limited to the above-mentioned embodiments, and may be variously modified.

As set forth above, according to an example of an acoustic resonator, because high crystallinity of the piezoelectric layer may be secured, the loss in the acoustic wave may be significantly reduced, and the kt2 value and performance of the acoustic resonator may be improved.

While this disclosure includes specific examples, it will be apparent to one of ordinary skill in the art that various changes in form and details may be made in these examples without departing from the spirit and scope of the claims and their equivalents. The examples described herein are to be considered in a descriptive sense only, and not for purposes of limitation. Descriptions of features or aspects in each example are to be considered as being applicable to similar features or aspects in other examples. Suitable results may be achieved if the described techniques are performed in a different order, and/or if components in a described system, architecture, device, or circuit are combined in a different manner, and/or replaced or supplemented by other components or their equivalents. Therefore, the scope of the disclosure is defined not by the detailed description, but by the claims and their equivalents, and all variations within the scope of the claims and their equivalents are to be construed as being included in the disclosure.

What is claimed is:

1. An acoustic resonator comprising:
- a resonating part comprising a first electrode, a second electrode, and a piezoelectric layer disposed between the first electrode and the second electrode; and
- a plurality of seed layers disposed on one side of the resonating part,
- wherein the plurality of seed layers comprise a first seed layer and a second seed layer,
- wherein an upper surface of the second seed layer corresponds to a (002) plane of hexagonal lattice.

2. The acoustic resonator of claim **1**, further comprising a substrate disposed on the opposite side of the plurality of seed layers from the resonating part.

3. The acoustic resonator of claim **2**, wherein an air gap is disposed between the substrate and the plurality of seed layers.

4. The acoustic resonator of claim **2**, wherein the resonating part further comprises a protection layer.

5. The acoustic resonator of claim **2**, wherein a membrane is interposed between the substrate and the plurality of seed layers, and
- an air gap is disposed between the substrate and the membrane.

6. The acoustic resonator of claim **5**, wherein the membrane comprises a plurality of membrane layers, and
- at least one membrane layer of the plurality of membrane layers is an etching stopper.

7. The acoustic resonator of claim **1**, wherein
- the first seed layer comprises a material having the same crystalline system as a material of the piezoelectric layer, and
- wherein the second seed layer comprises a material having the same unit cell geometry as a material of the first seed layer.

8. The acoustic resonator of claim **7**, wherein a thickness of the first seed layer or the second seed layer is within a range of 10 Å to 1,000 Å.

9. The acoustic resonator of claim **7**, wherein the piezoelectric layer, the first seed layer, and the second seed layer each comprise a material having a hexagonal crystal system.

10. The acoustic resonator of claim **9**, wherein the second seed layer comprises a material having a hexagonal close packed structure.

11. The acoustic resonator of claim **9**, wherein the piezoelectric layer comprises aluminum nitride or doped aluminum nitride,
- the first electrode comprises molybdenum,
- the first seed layer comprises aluminum nitride, and
- the second seed layer comprises titanium.

12. The acoustic resonator of claim **1**, wherein the piezoelectric layer comprises aluminum nitride or doped aluminum nitride,
- the first electrode comprises molybdenum,
- the first seed layer comprises titanium, and
- the second seed layer comprises aluminum nitride.

13. An acoustic resonator comprising:
- a resonating part comprising a first electrode, a second electrode, and a piezoelectric layer disposed between the first electrode and the second electrode; and
- a plurality of seed layers disposed on one side of the resonating part,
- wherein a first seed layer and a second seed layer of the plurality of seed layers, and the piezoelectric layer each comprise a material having a hexagonal crystal system.

14. The acoustic resonator of claim **13**, wherein the second seed layer comprises a material having a hexagonal close packed structure.

15. The acoustic resonator of claim **13**, wherein the piezoelectric layer comprises aluminum nitride or doped aluminum nitride,
- the first electrode comprises molybdenum,
- the first seed layer comprises aluminum nitride, and
- the second seed layer comprises titanium.

16. The acoustic resonator of claim **13**, wherein the piezoelectric layer comprises aluminum nitride or doped aluminum nitride,
- the first electrode comprises molybdenum,
- the first seed layer comprises titanium, and
- the second seed layer comprises aluminum nitride.

17. An acoustic resonator comprising:
- a resonating part comprising a first electrode, a second electrode, and a piezoelectric layer disposed between the first electrode and the second electrode;
- a plurality of seed layers disposed on one side of the resonating part, comprising a first seed layer and a second seed layer;
- a substrate disposed on the opposite side of the plurality of seed layers from the resonating part; and
- a plurality of membrane layers interposed between the substrate and the plurality of seed layers,
- wherein a lattice mismatch between the first seed layer and the second seed layer is less than or equal to 12.45%.

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